



Vulnerability of Bonny Coastal Communities to Sea Level Changes

Samuel B. Arokoyu², Mark Ogoro¹

¹Department of Geography and Environmental Management,
University of Port Harcourt, Port Harcourt, Nigeria

²Department of Geography and Environmental Management,
University of Port Harcourt, Port Harcourt, Nigeria

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ABSTRACT:- Increased inundation of coastlands could cause loss of lives, property, mangrove vegetation and wetlands. The present study examines the vulnerability of the Bonny Island and its inhabitants to inundation. Topographic map of the area was analysed using Arc GIS 9.3 tools. Digital Elevation Map (DEM) aided classification for different scenario of sea level rise. Inferential statistics which included Spearman's Rank Correlation and Pearson's Product Moment Correlation were used at 95 percent confidence level to determine the relationship between vulnerability classification and sea level rise scenario. Also the relationship between elevation of communities and vulnerability classification was determined. Hence, from the analysis of the topographic maps, it was observed that the region is generally vulnerable to sea level rise projection at 0.3m, 0.6m, and 1m through 10m.

The correlation coefficient (r) of the relationship between vulnerability classification and sea level changes was -0.13 while r^2 was 0.0169 and the coefficient of determination was 1.69 per cent, implying a weak relationship. Similarly the correlation coefficient (r) of the relationship between communities' elevation and vulnerability classification was 0.90 with r^2 equal 0.810 while the coefficient of determination was 81 per cent.

Keyword:- Inundation, Vulnerability, Coastland, Topographic, sea-level

I. INTRODUCTION

World climate change in the past includes among other 'the ice age (Pleistocene epoch) which was said to have began 2.5million years ago, the Holocene epoch (mid – Holocene maximum) which began about 6000 years ago (Robert *et al*, 2009). Today, 'almost all the world's oceanic coastline shows evidence of submergence during the last 15,000 years or so, due to the melting of Pleistocene ice. The most prominent result of submergence is the drowning of previous river valley which produces estuaries or long dendritic fingers of sea water projecting in – land' (McKnight, 1992). Vulnerability from a layman point of view is an individual, society's insecurity from natural and human – induced hazard. Though it could be broadly understood as the predisposition to be hurt should an event beyond a certain threshold of magnitude occurs and impact the individual, society, its environment, asset and infrastructures (Jorn, 2006). Human vulnerability to environmental change is not new, more than 9,000 years ago; the Sumerians of Mesopotamia started irrigating their lands to meet increased demand for food from growing population. Despite this, their civilization collapsed partly because of water logging and salinization (Mcknight, 1992).

In association to the growing awareness of the impact of global climatic trend on coastal communities, increased occurrence of extreme natural hazard events over the last three decades which amounted to an approximately six fold increase in associated economic damage and the IPCC, (1996) projection that sea level will rise between 0.3 and 1.0 meter by 2100. The impact of such rise may lead to the submergence of several settlements in the coastal area to include Bonny Island located within Nigeria Coastal Belt.

Views of possible coastal submergence or coastal vulnerability in Nigeria Niger Delta were expressed by Awosika *et al* (1992) among others. According to him, "If sea level rises, inundation could occur along more than 70% of the Nigeria coastline. Thus, with a 1m rise in sea level, up to 600km² of land would be at risk". In the wake of today's environmental challenges faced by humanity, everyone has been therefore made vulnerable

*Corresponding Author: Samuel B. Arokoyu

¹Department of Geography and Environmental Management,
University of Port Harcourt, Port Harcourt, Nigeria

to environmental impact of some kind with varied ability to adapt or cope with these changes or impact. Twiggs (2004) affirmed that between 1991 and 1995, natural disaster cause on an average 128,000 deaths per year and affected the lives of 136 million people out of which 97% of the death were in the developing countries.

Sequel to this global climatic trend, sea level rise should be of concern to low lying coastal region especially the Niger Delta region which is feared to be barely above the high tide level in most of its communities (Oyegun, 2007).

Therefore, there is urgent need to map the extent of human and facilities in – security / vulnerability to such environmental changes. This would help in preparing to mitigate the effects before occurrence, thereby managing our environment by serving the people.

II. THE STUDY AREA

Nigeria has a shoreline of 800km² in length out of which the Niger Delta constitute about 60% of the Nigerian coastline (Oyegun, 2007). Bonny Island is located in the Niger Delta region of Nigeria. It comprises of Bonny Town, New Finima and other smaller settlements. Its coastline located along the Atlantic Ocean is classified as a passive margin coast because ‘major tectonic activities within the Atlantic Ocean occurs in the centre of the ocean along the Mid – Atlantic Ridge, whereas the coastal area are tectonically passive, with little mountain building or volcanic activities. The Island is about 40 kilometres from the state capital Port Harcourt.

The 1991 population figure of Nigeria put the Island population at 33,667 persons, out of which 18,282 are male and 15,385 female. The Island as categorized as a passive margin cost subject to the low relief structure with broad coastal plains and wide submerged edge of the continent called continental shelves (Robert et al, 2000).

2.1 LANDFORM AND DRAINAGE

The Island comprises two landform namely; the beach ridge barrier and tidal flats (Bonny Master Plan, 2002). The Beach Ridge Barrier is a series of elongated sandy ridge with intervening trough. They run roughly parallel to the coastline and have been formed by the opposing action of the Niger River extending its seaward and the Atlantic Ocean currents impinging on the coast as shown in plate 1 & 2 below



Photo: Author's Fieldwork, 2012

Plate 1: Coast of Bonny Island Showing Seaward Extension of Delta



Photo: Author's Fieldwork, 2012

Plate 2: Coast of Bonny Island Showing the Impact of Atlantic Ocean on the Coast

These barriers form the break between the ocean and hinterland and rise some 3 meter or so above sea level (Bonny Master Plan, 2002).

Inland are a series of abandoned beach ridge and depression that also run parallel to the coast and which are isolated from the effects of tidal inundation. The tidal flats are extensive flats depression that lies behind the beach ridge barrier shown in plate 3 below



Photo: Author's Fieldwork, 2012

Plate 3: The reclaimed tidal flat behind a fortified beach ridge barrier

The course of the Bonny River which is the largest in the study area flow south easterly in to a large water basin at the centre of the study area from where it flows southerly and then slightly south westerly as it empties in to the Bright of Brafia. Its flow is between the two neighbouring estuaries of the Atlantic coastline formed by the New Calabar River to the west and the Andoni River to the east. A further major connection formed by the Cawthorne channel link the New Calabar and Bonny River estuaries. Two other rivers; the Oboama Toru and the Huge Channel run approximately parallel to the Cawthorne channel. East of the Bonny

River, is the Opobo channel which links up with the Andoni River and flows in a generally parallel course to it. The Opobo Channel flows generally east to west draining severity of creeks. The largest of which is located at the eastern boundary.

2.2 CLIMATE

The climate of the area is generally hot, very humid tropical. The mean annual rainfall is very high at over 4,000 mm with no month having less than 50 mm therefore putting the growing season at 330 days or more with an average monthly temperature in the range of 26°C, mean annual potential evapo-transpiration estimated to be 1100 mm.

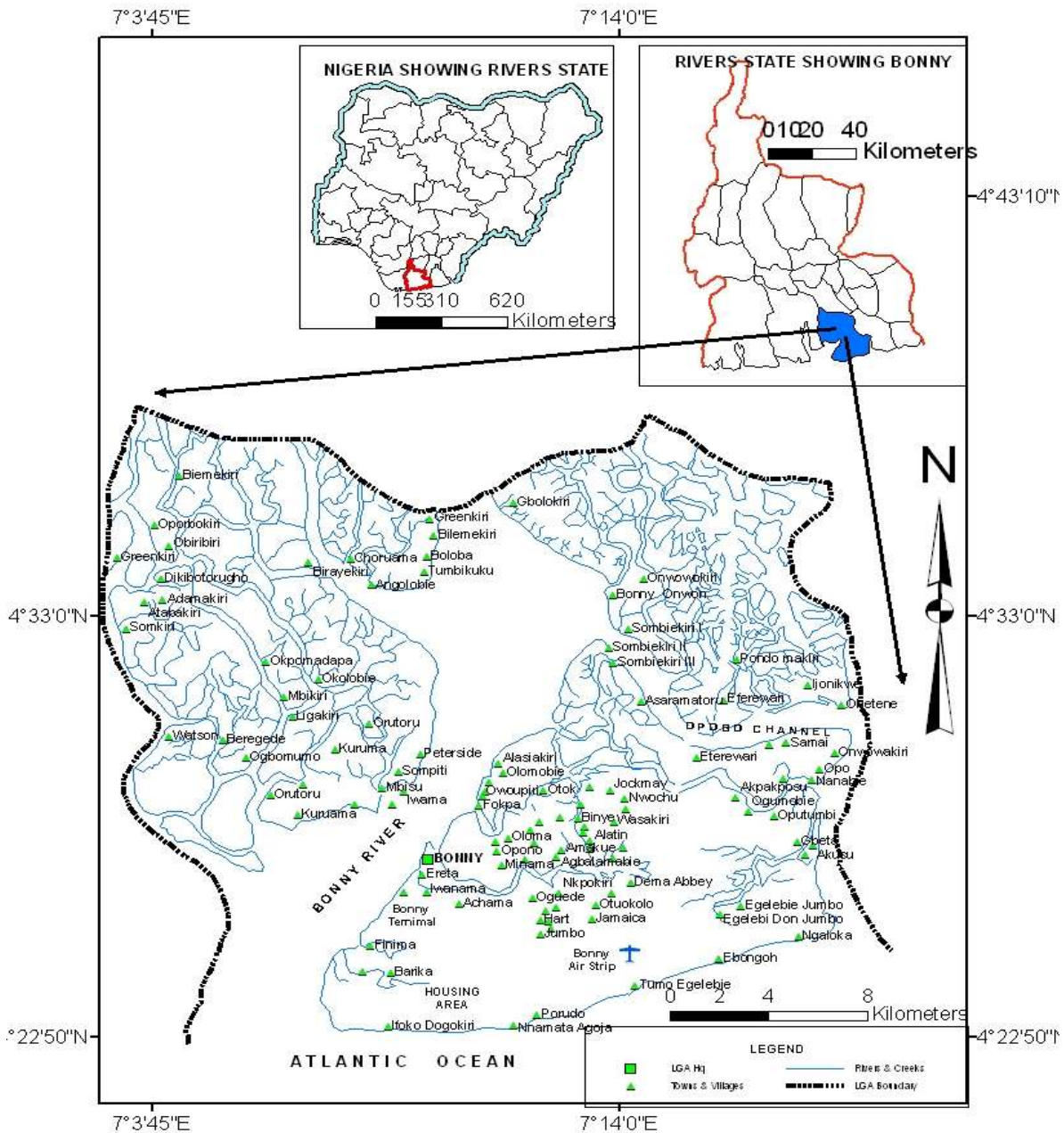
2.3 POPULATION AND SETTLEMENT

Bonny Island has a population of 33,667 out of which 18,282 are male and 15,385 female (NPC, 1991). The settlement comprises large and small settlements these settlements are mostly located in relation to transportation, combination of highways and water ways (Bonny Master Plan, 2002). The concentration of population resides in the main urban area, which are also located close to the major industrial activities.

2.4 LAND USE

The description of land use could be categorized in to several heading; Housing, Industry, Commercial, other land uses

1. **Housing:** In 2001, 14,000 dwelling units were distributed throughout the zone. These dwellings units area are either single or two stores in height and constructed in concrete with zink, metal, asbestos roofing sheer while in other rural area dwelling are made of concrete mud, zink, wood with thatched zink roofing sheet.
2. **Industry:** The principal Industrial activities are extraction, processing, storage and export of petroleum products. The major companies operating in the area are
 - ✓ Shell Petroleum Development Company (SPDC) whose responsibilities are extraction, storage and export of crude oil.
 - ✓ Nigeria Liquefied Natural Gas (NLNG) deals mainly with the processing and export of liquefied natural gas.
 - ✓ Mobil oil company were involves in the collection, storage and export of petroleum products
 - ✓ Other industries where involved in activities such as construction, fabrication, manufacturing and service provision.
3. **Commerce:** The principal areas of commercial activities are in the main urban areas where activities tend to be limited to markets and branch offices of major companies. Markets are spatially located with emphasis on area of high population density.
4. **Transportation:** This can be categorized in to two;
 - i Inland
 - ii Water
 - i Inland mode of transportation is dominated by motorcycle, car, mini buses. The most pre dominant mode of Inland transport is the motorcycle which is attributed to it relatively low cost of purchase.
 - ii Water Transportation: this is the only significant mode of transportation to the island as Bonny Island is only assessable by boat and air. Despite the presence of numerous rivers and creeks, the actual amount of water navigable by large river craft is very limited inland. As a result small canoes, speedboats and raft are widely used. These vessels have limited carrying capacity though with an advantage of upstream penetration. The most widely used water transports are double engine speedboats that are operated by private operators, local government and Nigeria Liquefied Natural Gas (NLNG).



Source: Lands & Survey Division, Governor's Office, 1994 Rivers State.
Digitized by Author, 2012.

Figure 4: Study Area Showing Water Bodies and Communities

III. OBJECTIVES

- I. To identify, map, classify vulnerable areas of Bonny to sea level changes
- II. Estimate future vulnerability given scenarios of sea level changes
- III. To recommend strategies to reduce the peoples' vulnerability and increase adaptation strategies to sea level changes.

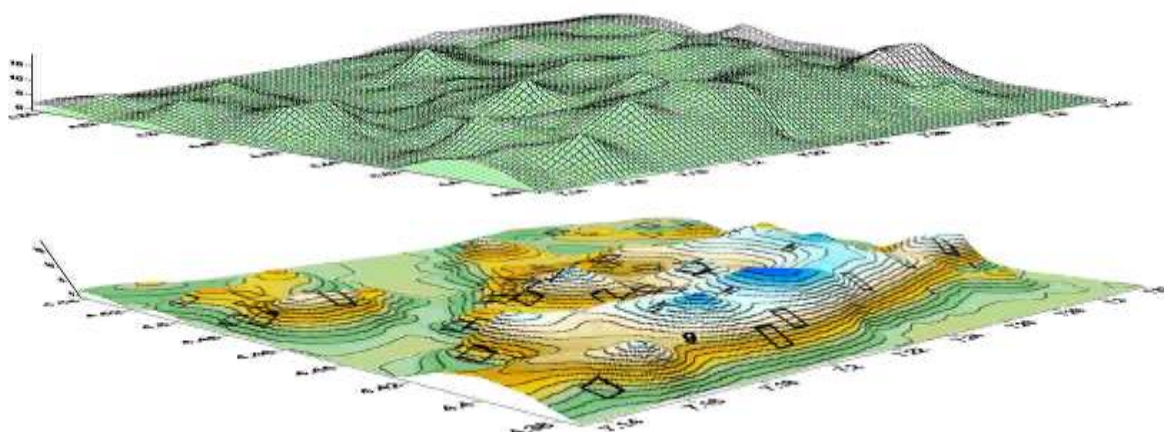
IV. METHODOLOGY

- I. The Topographic map of the study area was scanned and imported into the ArcGIS 9.3 environment where it was geo – referenced to geographic coordinate system. X, y, and z data were generated from the contour lines in the topographic map using Script Avenue of the Arc view 3.3 this aided the generation of the Digital Elevation Model (DEM) through interpolation method called kriging. The DEM were used to classify all the parameters in to three; Highly, Moderately and Lowly vulnerable areas.

II. The relationship between communities elevation and vulnerability to inundation was tested at 95% confidence level using the Pearson's Product Moment Correlation analysis. Where the predictor (x) was communities' elevations and the predicted (y) was their corresponding vulnerable rating either as Highly, Moderately and lowly vulnerable areas.

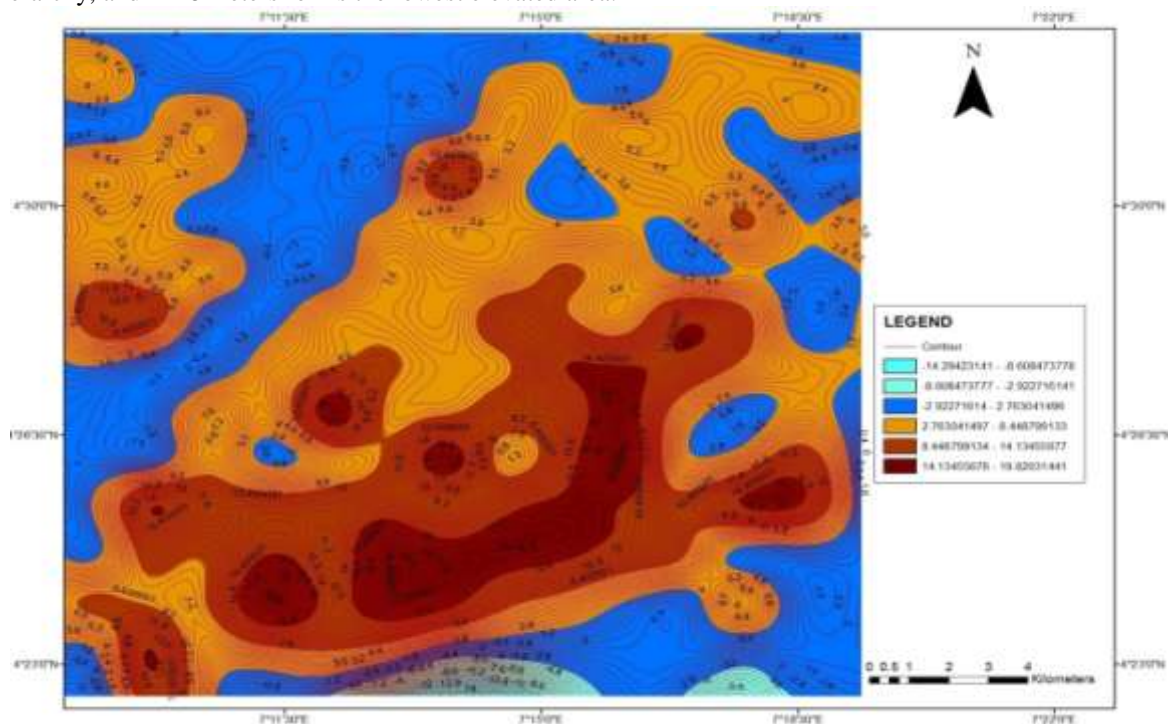
V. VULNERABILITY MAPPING OF BONNY ISLAND

The three Dimensional (3D) surface analyses of Bonny Island were derived from the contour map of the Island. It is helped in showing the surface elevation or relief of the Island as shown in fig. 5 below



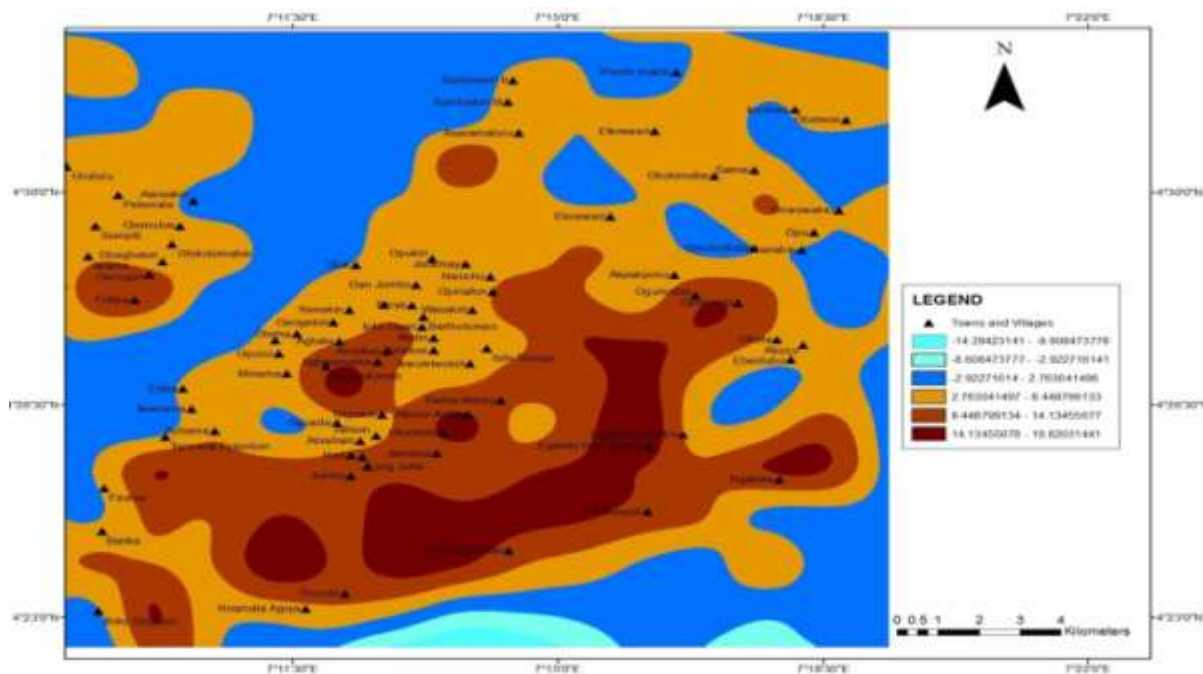
Source: Author's Field Work/Analysis, 2012
Figure 5 3D Surface Analysis of Bonny Island

The DEM was used to generate an as shown in Fig. 6. From the map, it could be observed that 14 - 19 meter above mean sea level forms the highest elevated area, 8 – 14 meter above mean sea level is the next in hierarchy, and 2 – 8 meters forms the lowest elevated area.



Source: Author's Field Work/Analysis, 2012
Figure 6 Digital Elevations and Contour Map of Bonny Island

From analysis, 60 communities' lies within 2 – 8 meters above mean sea level, 22 communities are within 8 – 14 meter above sea level, and 3 communities are above 14 meters as shown in fig. 7.



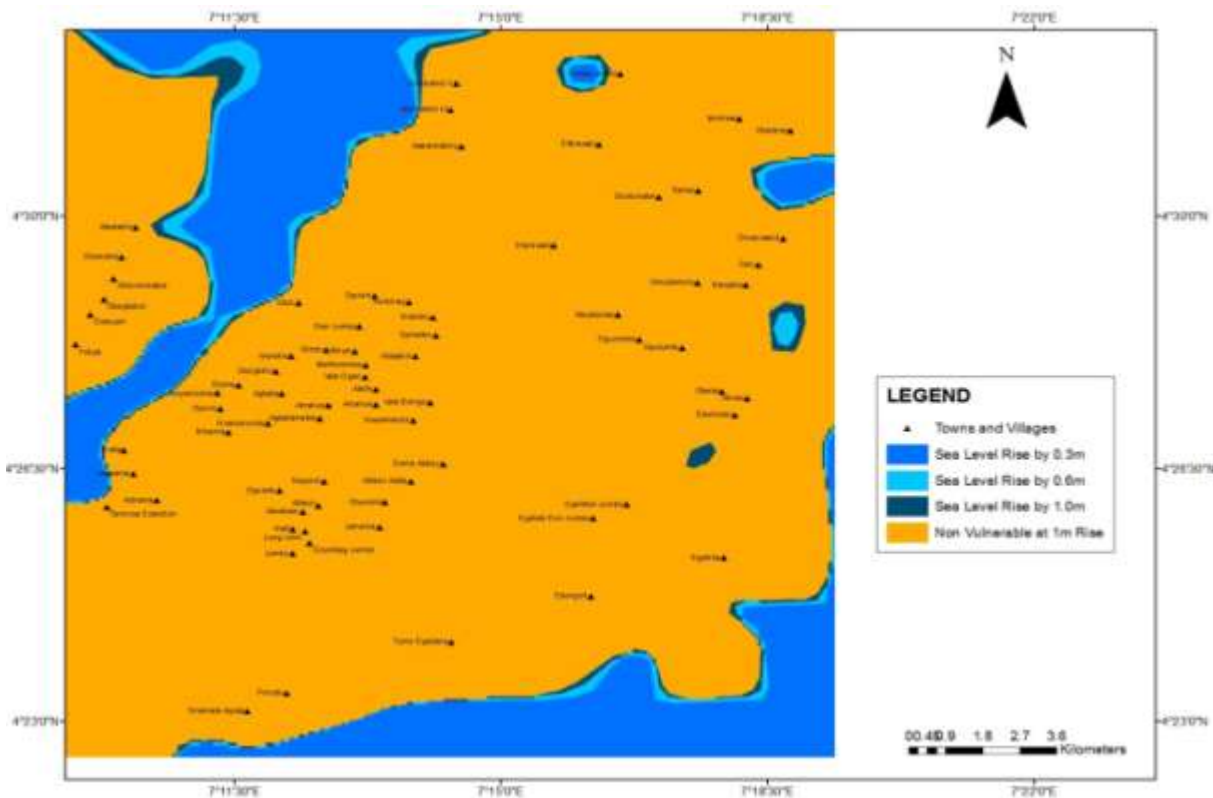
Source: Author’s Field Work/Analysis, 2012
Figure 7 Digital Elevations and Community Map of Bonny Island

The imagery obtained from google earth shows locational trend (Spatial Exposure) of built-up infrastructure in relation to the Atlantic Ocean as shown in Fig. 8.



Source: Author’s Field Work/Analysis, 2012
Figure 8 Spatial exposure of Bonny Island

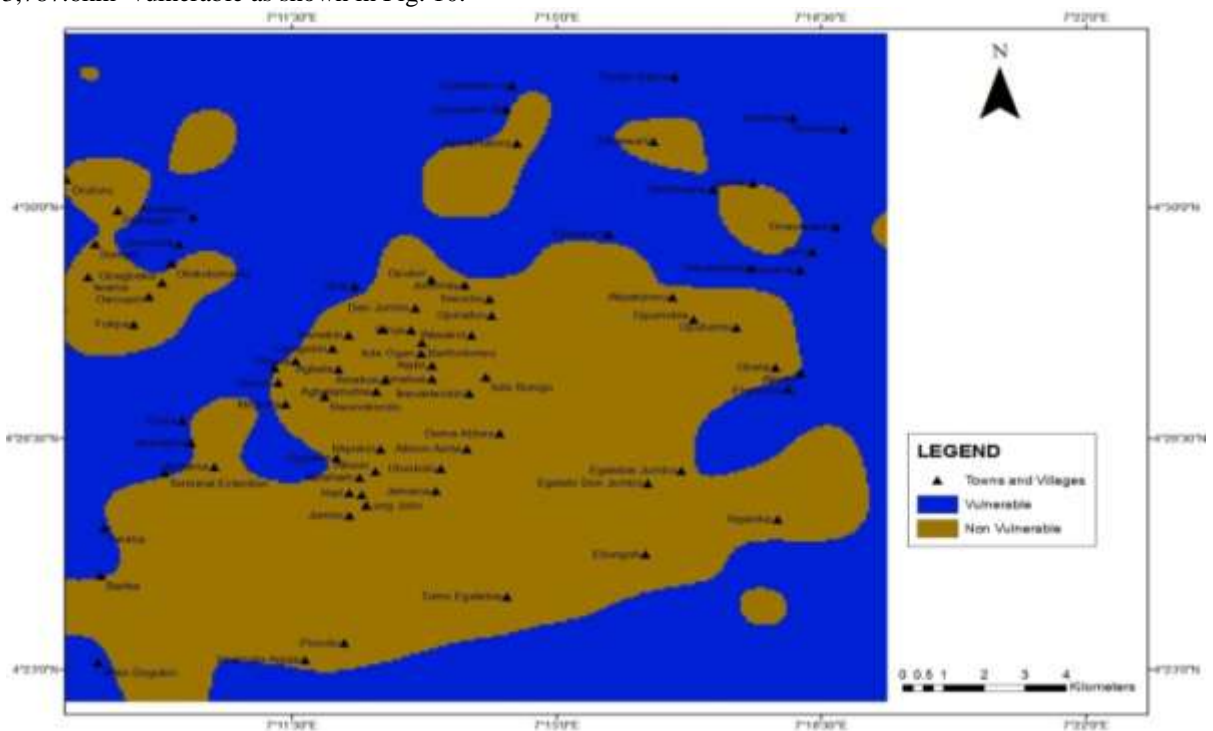
At a rise in sea level by 0.3m, 0.6m and 1m as projected by (IPCC, 2006; Oyegun, 2007) The analysis of vulnerability to land inundation as shown in figure 9 indicates that 1,621km² of the land area would be inundated at a 0.3m rise in sea level, 261.6km² of land at risk of inundation at a 0.6m rise in sea level, and 221.3km² of land would be inundated at a 1 m rise in sea level. Cumulatively therefore over 482.9km² of land is vulnerable to inundation at a 1 m rise in sea level as predicted by IPCC 2006 and Oyegun, 2007.



Source: Author's Field Work/Analysis, 2012

Figure 9 Spatial vulnerability to land inundation at, 0.3, 0.6, & 1meter rise in sea level

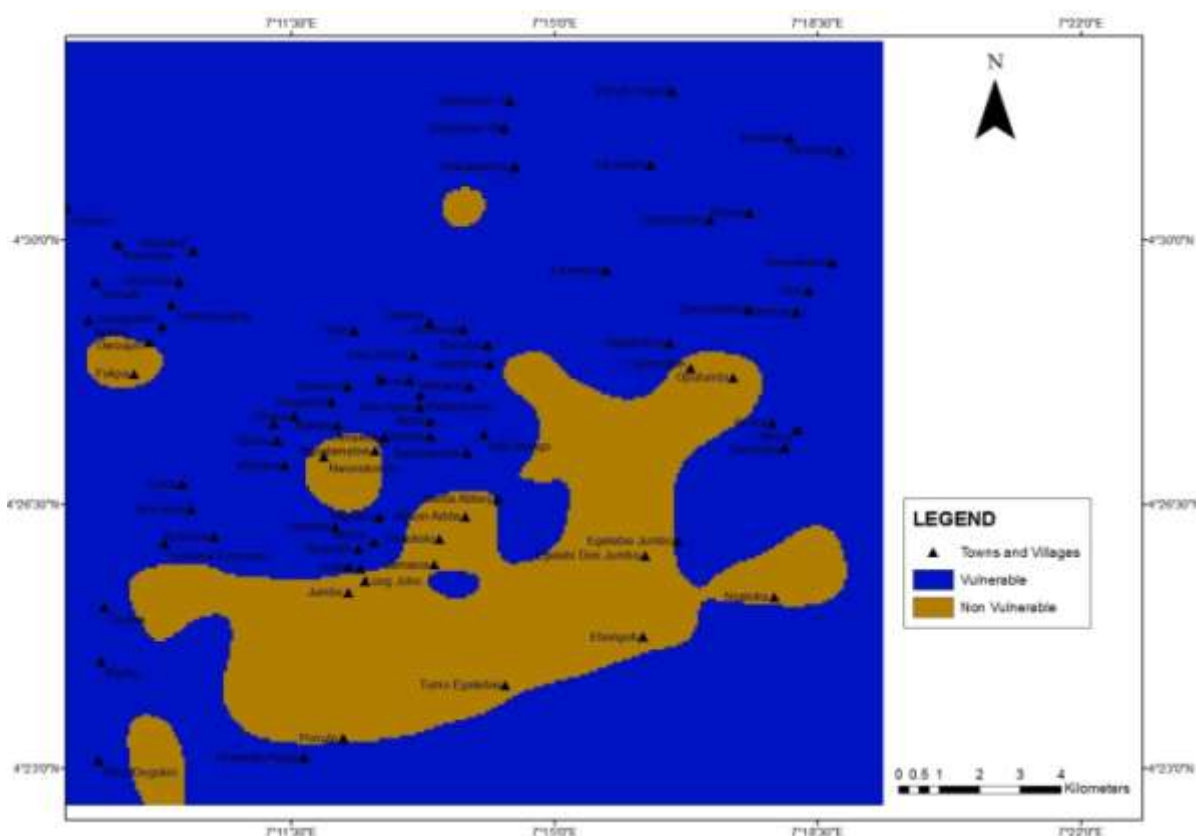
Vulnerability of the settlements within the coastal belt of bonny to 5 meter sea level rise as projected by (Tol et al 2008; Vaughan, 2008). The analysis revealed from that at 5 meter sea level rise, over 25 settlements would be vulnerable to annihilation and 820.7km² of land would be inundated making a cumulative land area of 3,787.6km² vulnerable as shown in Fig. 10.



Source: Author's Field Work/Analysis, 2012

Figure 10 Spatial vulnerability to land inundation at, 5meter rise in sea level

Vulnerability of the settlements within the coastal belt of bonny to 10 meter sea level rise as projected by (The United States Geological Survey (USGS) in Robert et al, 2009; IPCC, 2009). The analysis revealed from that at 10 meter sea level rise, over 63 settlements would be vulnerable to annihilation and 526.99km² of land would be inundated making a cumulative land area of 6,777.6km² vulnerable as shown in Fig. 11.



Source: Author's Field Work/Analysis, 2012

Figure 11 Spatial vulnerability to land inundation at, 10meter rise in sea level

VI. TESTING VULNERABILITY TO INUNDATION IN RELATION TO ELEVATION

Table 1 Vulnerability to Inundation in relation to Elevation

Communities Elevations (x) (m)	Corresponding Vulnerability Rating (y)	Vulnerability Rating	XY	X ²	Y ²
3	1	Highly Vulnerably	3	9	11
8	2	Moderately Vulnerable	16	64	4
9	2	Moderately Vulnerable	18	81	4
16	3	Lowly Vulnerable	48	256	9
9	2	Moderately Vulnerable	18	81	4
7	2	Moderately Vulnerable	14	49	4
3	1	Highly Vulnerably	3	9	1
12	3	Lowly Vulnerable	36	144	9
14	3	Lowly Vulnerable	42	196	9
14	3	Lowly Vulnerable	42	196	9
10	2	Moderately Vulnerable	20	100	4
11	3	Lowly Vulnerable	33	121	9
10	2	Moderately Vulnerable	20	100	4
7	2	Moderately Vulnerable	14	49	4
10	2	Moderately Vulnerable	14	100	4
12	3	Lowly Vulnerable	36	144	9
16	3	Lowly Vulnerable	48	256	9
9	2	Moderately Vulnerable	18	81	4

6	2	Moderately Vulnerable	12	36	4
16	3	Lowly Vulnerable	48	256	9
8	2	Moderately Vulnerable	16	64	4
14	3	Lowly Vulnerable	42	196	9
7	2	Moderately Vulnerable	14	49	4
8	2	Moderately Vulnerable	16	64	4
6	2	Moderately Vulnerable	12	36	4
7	2	Moderately Vulnerable	14	49	4
8	2	Moderately Vulnerable	16	64	4
5	2	Moderately Vulnerable	10	25	4
5	2	Moderately Vulnerable	10	25	4
4	1	Highly Vulnerably	4	16	1
5	1	Highly Vulnerably	5	25	4
6	2	Moderately Vulnerable	12	36	4
1	1	Highly Vulnerably	1	1	1
5	1	Highly Vulnerably	6	25	1
14	3	Lowly Vulnerable	42	196	9

Table 1 continued

Communities Elevations (x) (m)	Corresponding Vulnerability Rating (y)	Vulnerability Rating	XY	X ²	Y ²
3	1	Highly Vulnerably	3	9	1
7	2	Moderately Vulnerable	14	49	4
7	2	Moderately Vulnerable	14	49	4
7	2	Moderately Vulnerable	14	49	4
6	2	Moderately Vulnerable	12	36	4
6	2	Moderately Vulnerable	12	36	4
6	2	Moderately Vulnerable	12	36	4
7	2	Moderately Vulnerable	14	49	4
8	2	Moderately Vulnerable	16	64	4
8	2	Moderately Vulnerable	16	64	4
9	2	Moderately Vulnerable	18	81	4
16	3	Lowly Vulnerable	48	256	9
16	3	Lowly Vulnerable	48	256	9
7	2	Moderately Vulnerable	14	49	4
7	2	Moderately Vulnerable	14	49	4
7	2	Moderately Vulnerable	14	49	4
9	2	Moderately Vulnerable	18	81	4
9	2	Moderately Vulnerable	18	81	4
1	1	Highly Vulnerably	1	1	1
4	1	Highly Vulnerably	4	16	1
8	2	Moderately Vulnerable	16	64	4
13	3	Lowly Vulnerable	39	169	9
6	2	Moderately Vulnerable	12	12	4
3	1	Highly Vulnerably	3	9	1
2	1	Highly Vulnerably	2	4	1
2	1	Highly Vulnerably	2	4	1
2	1	Highly Vulnerably	2	4	1
3	1	Highly Vulnerably	3	9	1
6	2	Moderately Vulnerable	12	36	4
6	2	Moderately Vulnerable	12	36	4
6	2	Moderately Vulnerable	12	36	4
4	1	Highly Vulnerably	4	16	1
2	1	Highly Vulnerably	2	4	1
3	1	Highly Vulnerably	3	9	1

4	1	Highly Vulnerably	4	16	4
6	2	Moderately Vulnerable	12	36	1
4	1	Highly Vulnerably	4	16	1
4	1	Highly Vulnerably	4	16	4
7	2	Moderately Vulnerable	14	49	4
7	2	Moderately Vulnerable	14	49	4
7	2	Moderately Vulnerable	14	49	4
6	2	Moderately Vulnerable	12	36	4
7	2	Moderately Vulnerable	14	49	4
6	2	Moderately Vulnerable	12	36	4
4	1	Highly Vulnerably	4	16	1
7	2	Moderately Vulnerable	14	49	4
590	154		1,293	5,388	326

Where Pearson's Product Moment Correlation:

$$\frac{N \sum XY - (\sum X)(\sum Y)}{\sqrt{\{N(\sum X^2) - (\sum X)^2\}\{N(\sum Y^2) - (\sum Y)^2\}}} \dots\dots\dots(1)$$

rho = 0.90

Coefficient of determination = 81%

81% of the vulnerability to inundation is determined by elevation. Other factors other than elevation account for 19% of vulnerability to inundation

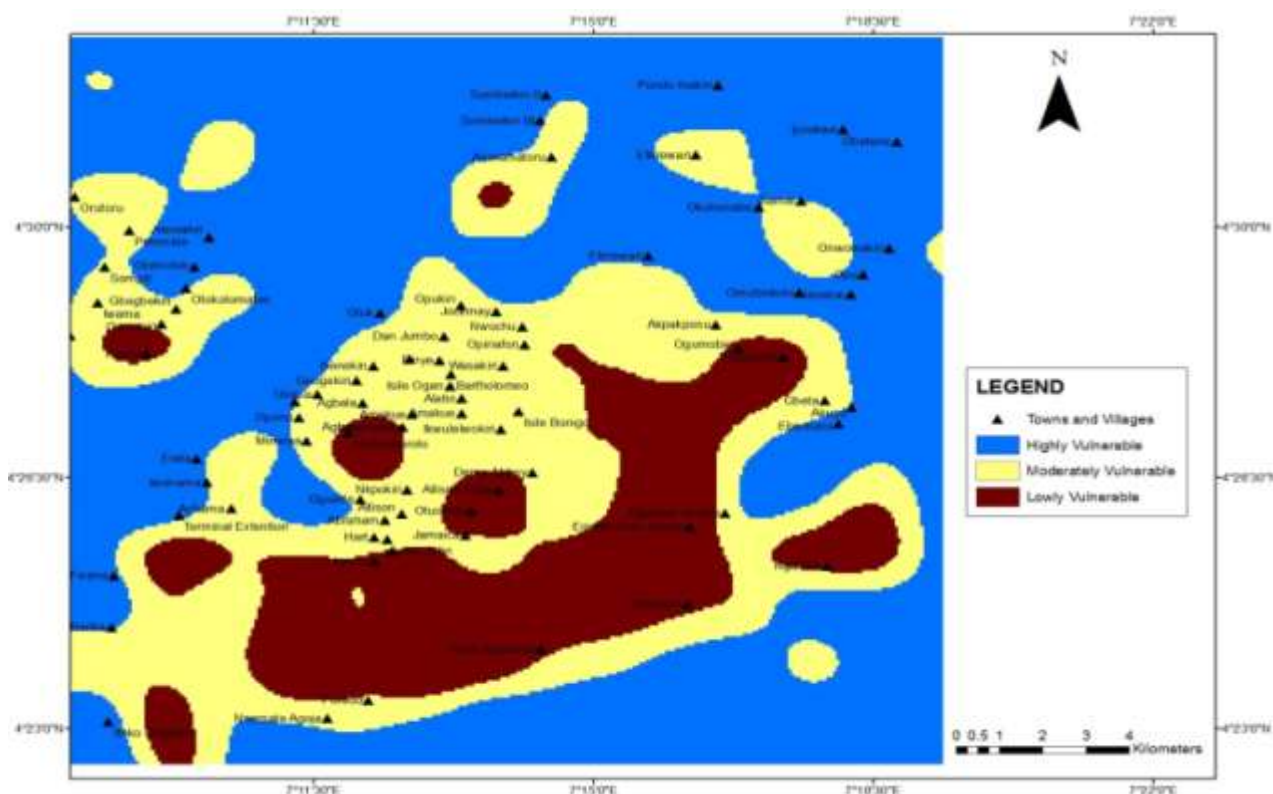
Test of Significance

$$= t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \dots\dots\dots(2) = 18.2 \text{ (rho Calculated)}$$

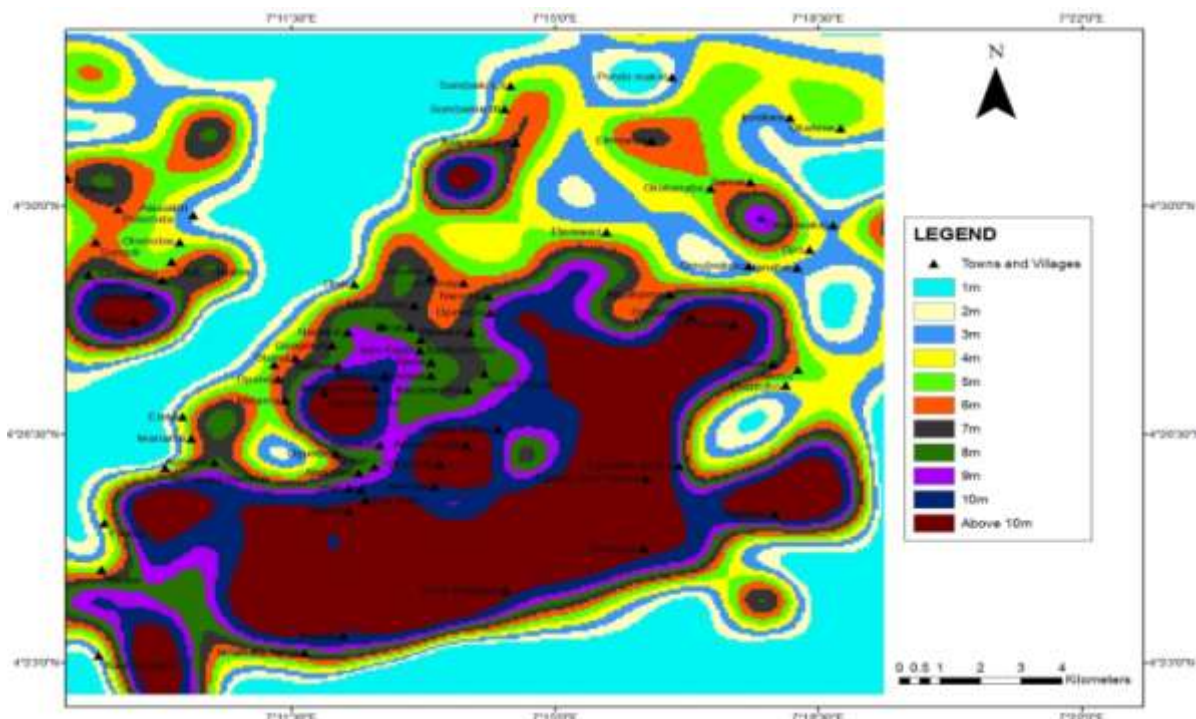
Degree of Freedom = N - 2 = 81 - 2 = 79

Therefore, r (critical) = **1.98**

Since the calculated table value of 18.2 is higher than the critical value of 1.98 at 79 degree of freedom and 95% confidence level, Hence, there is statistically significance relationship between elevation of bonny coastal communities and their vulnerability to inundation'.



Source: Author's Field Work/Analysis, 2012
Figure 12 Vulnerability to Inundation at 5 & 10 Meters Sea Level Rise



Source: Author's Field Work/Analysis, 2012

Figure 13 Vulnerability to Inundation at the range of 1 to 10Meters Sea Level Rise

VII. CONCLUSION

Sea level changes and vulnerability of the coastal settlements has been analyzed using integrated approach of satellite imageries, GIS tools and Quantitative Techniques. It reveals that the coastal settlements of Bonny Island are vulnerable to sea level changes. The study therefore recommends that mangrove vegetation on the area should be protected, coastal and marine processes should be monitored, public enlightenment programmes, workshops, seminars should be organized periodically for the residents to make them aware of their vulnerability. Also, early warning and tidal monitoring systems should be installed to monitor sea level changes that would occur in the area.

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